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Monitoring of Fluoride in Groundwater Resources of Iran

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Abstract Fluoride concentration in groundwater resources that used as the source of drinking water in urban areas of Iran was determined. All of the groundwater wells located in urban areas were monitored in 2008. Fluoride concentration of water samples was measured using SPADNS method. The nationwide mean fluoride concentration in the groundwater resources was found to be 0.47 ± 0.28 (± standard deviation) mg/L. Only in Bushehr Province, the provincial mean fluoride level in the groundwater resources was higher than the WHO guideline value of 1.5 mg/L (1.86 ± 0.86 mg/L). At nationwide level, the portion of extracted groundwater with fluoride concentration lower than the minimum permissible level of 0.5 mg/L, desirable fluoride range of 0.5–1.5 mg/L and elevated fluoride level was 69.2, 29.3 and 1.4%, respectively. In the areas with low fluoride content drinking water, it is recommended that fluoride is absorbed by use of high fluoride content foods and beverages. The recommendations for the circumstances with excessive fluoride content of drinking water are provision of drinking water from alternative sources and defluoridation of drinking water by point-of-use systems, respectively.

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Earth's crust contains fluoride in the average concentration of 0.3 g/kg and background concentration of fluoride in the air throughout the world is about 3 ng/m^3. Entrance of fluoride into the water environment is mainly occurred through natural resources. In addition industries that use inorganic fluoride-containing materials, such as aluminum, phosphate fertilizer, steel, glass fiber, brick, tile and ceramic production industries are the most important artificial resources of fluoride entrance to water bodies (WHO 1996, 2006; Kalinić et al. 2005). Fluoride is an essential microelement for animals and human that its intake in the proper extent protects teeth against carries especially in childhood, but excessive exposure to fluoride can damage skeletal tissues (bones and teeth). However the minimum nutritional requirement of fluoride is not determined exactly until now, but the risk of adverse effects on skeleton may be increased at total fluoride intakes above 6 mg/day and at fluoride intake of 14 mg/day, clear adverse skeletal effects may be observed (Hillier et al. 2000; Pehrsson et al. 2006; WHO 2006).

Fluoride can be absorbed by human body via food, drinking water, toothpaste, mouthwash products and air, but air is not usually a major source of uptake. The digestive system is the main route of fluoride intake. After oral uptake, about 75–90% of ingested fluoride is absorbed in the gastrointestinal tract, transported via the blood and mainly accumulated into teeth and bones. Drinking water is the primary source of fluoride intake in the majority of communities. Food is the other important source of fluoride intake. Fluoride can be found in any kind of foodstuff, but the content of some food such as curly kale, endive, fish

and tea is higher than the others (WHO 1996; Fawell et al. 2006; Meenakshi and Maheshwari 2006). Fluoride concentration in water resources is mainly depended to the type of rock and soil that the water flows through or on them. Many epidemiological studies indicated that the long-term uptake of fluoride via drinking water with elevated fluoride concentration resulted in adverse effects on skeletal tissues; therefore World Health Organization (WHO) established a guideline value of 1.5 mg/L for this element (WHO 2006; Singh et al. 2007; Chaudhary et al. 2008). The protective effect of fluoride against teeth carries usually increases with fluoride concentration of drinking water from 0.5 to 2.0 mg/L, but depending on volume of water consumed and fluoride intake through other resources, dental fluorosis may be revealed at drinking water concentrations between 0.9 and 1.2 mg/L (WHO 2006; Fawell et al. 2006; Meenakshi and Maheshwari 2006).

The Country Iran is located in southern part of north moderate zone between 25°03′ and 39°47′ of northern latitude and 44°14′ and 63°20′ of eastern longitude. Iran is the eighteenth largest country in the world with area of 1,648,195 km^2. The country has a population of over seventy million (National Geoscience Database of Iran 2009). In the current Iranian standards for drinking water quality (revised in 1992), 6 standard ranges of fluoride concentration were established for various ranges of the annual average of maximum daily temperatures based on the fact that water consumption increases in warmer climates. These standard ranges are given in Table 1 (Institute of Standards and Industrial Research of Iran 1992). In Iran, fluoride content of drinking water have been investigated in some limited areas (Dobaradaran et al. 2008; Poureslami et al. 2008); however the overall situation of drinking water concerning fluoride throughout the country has not been determined until now.

This paper represents the fluoride concentration in groundwater resources utilized for community water supply in urban areas of Iran during 2008. National and provincial mean fluoride levels in groundwater resources were determined and the portion of extracted water with insufficient or elevated fluoride concentration along with feasible measures for improvement of drinking water quality regarding fluoride was exhibited.

Table 1 Iranian standard of drinking water quality for fluoride

Annual average of maximum daily temperatures (°C)	Minimum permissible level (mg/L)	Desirable level (mg/L)	Maximum permissible level (mg/L)
10–12	1.1	1.2	2.4
12–14.6	1.0	1.1	2.2
14.6–17.7	0.9	1.0	2.0
17.7–21.5	0.8	0.9	1.8
21.5–26.5	0.7	0.8	1.6
26.5–32.5	0.6	0.7	1.4

Materials and Methods

This study was conducted in urban areas of Iran by Iranian Water and Wastewater Engineering Company in cooperation with 40 regional water and wastewater companies located in 30 provinces all across the country. Since this study was performed at nationwide level, general status of community water supply was surveyed prior to monitoring of fluoride in drinking water.

In urban areas of Iran, approximately 67% of municipal water is provided from groundwater resources. Thus, in this study for preparation of basic data about fluoride concentration of drinking water consumed in the country, all of the groundwater wells located in urban areas that used for drinking water were monitored in 2008. Number of sampling sites was 5,314. To account for seasonal variation of fluoride in water, sampling in each site was replicated 3–4 times in various seasons and the mean value was presented. Fluoride concentration of water samples was determined using SPADNS method according to instruction of Standard Methods (APHA/AWWA/WEF 1998). The minimum detectable level of the SPADNS method was 0.02 mg/L. Results of the monitoring program were analyzed using Microsoft Excel and SPSS.

Results and discussion

Results of the survey indicated that in 2008 urban population of the country was 49.6 million people (about 71% of population of the county) and approximately 98.4% of them were served by public water systems. Total capacity of these systems was 8.0 billion cubic meters of water annually. The portion of surface and groundwater in the water supply was 33 and 67%, respectively. In the systems with surface water resources, water treatment train usually consisted of coagulation, flocculation, sedimentation, filtration and disinfection for turbidity and microbial quality control. In contrast, water treatment process in the systems with groundwater resources often contained only disinfection. None of the water systems had fluoridation or defluoridation units; therefore fluoride concentration of treated water would be approximately equal to fluoride content of raw water (Iranian Water and Wastewater Engineering Company 2008).

The overall situation of groundwater resources regarding fluoride content is given in Table 2 and shown in Fig. 1. As presented in Table 2, the nationwide mean

Table 2 Fluoride concentration in groundwater resources of Iran

No.	Province	Number of sampling sites	Flowrate (L/s)	Portion of groundwater in water supply (%)	Mean (mg/L)	Standard deviation: SD (mg/L)	Coefficient of variation (%)	Weighted mean by flowrate (mg/L)	Range (mg/L)	2.5 Percentile (mg/L)	97.5 Percentile (mg/L)
1	Ardebil	71	1,026	55	0.44	0.19	42.89	0.42	0.11–0.95	0.19	0.92
2	Bushehr	15	131	100	1.86	0.86	46.25	1.71	1.11–4.06	1.15	3.77
3	Chahar Mahal & Bakhtiari	122	1,465	100	0.61	0.23	38.33	0.59	0.11–1.25	0.20	1.06
4	East Azarbaijan	245	3,851	58	0.35	0.13	38.74	0.32	0.10–0.95	0.13	0.62
5	Esfahan	231	4,519	35	0.44	0.23	51.63	0.42	0.10–1.41	0.16	0.93
6	Fars	400	8,973	100	0.53	0.42	77.74	0.48	<0.02–2.94	0.09	2.12
7	Gilan	166	1,169	25	0.45	0.26	57.77	0.46	<0.02–1.56	0.03	0.95
8	Golestan	150	1,900	94	0.38	0.13	34.68	0.38	<0.02–1.08	0.16	0.75
9	Hamedan	145	1,967	68	0.45	0.24	54.61	0.43	<0.02–1.28	0.02	0.95
10	Hormozgan	65	808	33	0.97	0.57	58.60	0.76	0.17–3.15	0.25	2.37
11	Ilam	39	785	61	0.29	0.17	57.46	0.24	<0.02–1.09	0.10	0.72
12	Kerman	259	5,271	100	0.26	0.27	104.48	0.25	<0.02–1.11	<0.02	0.95
13	Kermanshah	167	4,140	100	0.23	0.19	83.39	0.20	<0.02–1.35	<0.02	0.65
14	Khuzestan	76	7,472	50	0.48	0.24	50.15	0.47	<0.02–1.47	0.15	1.00
15	Kohgiluyeh & Buyer Ahmad	40	1,022	100	0.30	0.18	60.41	0.29	<0.02–0.90	0.06	0.70
16	Kordestan	85	1,431	53	0.39	0.20	50.84	0.39	<0.02–0.82	<0.02	0.74
17	Lorestan	95	3,733	94	0.53	0.34	64.26	0.52	<0.02–1.13	0.07	1.09
18	Markazi	142	3,320	100	0.35	0.21	59.02	0.32	0.09–1.10	0.12	0.86
19	Mazandaran	211	6,513	100	0.37	0.29	79.20	0.36	<0.02–2.40	0.04	0.96
20	North Khorasan	75	1,073	100	0.62	0.34	54.62	0.61	<0.02–1.76	<0.02	1.29
21	Qazvin	106	2,334	99	0.50	0.29	57.53	0.49	0.03–2.41	0.14	1.30
22	Qom	34	935	34	0.82	0.29	35.44	0.84	<0.02–1.51	0.07	1.28
23	Razavi Khorasan	632	8,688	85	0.42	0.20	49.18	0.40	<0.02–2.86	0.09	1.37
24	Semnan	78	1,477	88	0.64	0.27	41.43	0.58	0.04–1.61	0.18	1.33
25	Sistan & Baluchestan	110	2,440	100	0.46	0.31	67.45	0.41	<0.02–1.52	<0.02	1.13
26	South Khorasan	62	989	100	0.48	0.26	53.27	0.50	0.10–1.72	0.11	1.12
27	Tehran	1,141	26,599	53	0.35	0.25	71.36	0.33	<0.02–1.88	0.10	1.41
28	West Azarbaijan	173	3,769	73	0.66	0.66	98.66	0.59	0.17–5.00	0.25	3.36
29	Yazd	82	2,672	100	0.81	0.43	53.47	0.86	0.15–2.70	0.27	2.20
30	Zanjan	97	1,807	100	0.34	0.15	45.53	0.30	<0.02–0.81	0.05	0.66
31	Nationwide	5,314	112,595	67	0.47	0.28	60.76	0.44	<0.02–5.00	0.11	1.33

fluoride concentration in the groundwater resources was 0.47 ± 0.28 (±standard deviation: SD) mg/L. In 21 provinces out of 30 provinces of Iran, mean fluoride concentration in the groundwater resources was lower than the minimum permissible level of 0.5 mg/L according to WHO guideline. Lowest provincial mean concentration of fluoride was 0.23 ± 0.19 mg/L that was observed in Kermanshah Province. Highest fluoride level in an individual water sample was 5.00 mg/L that was reported in Maku City, West Azarbaijan Province. In this region, presence of high fluoride content volcanic rocks can be accounted as the main reason of the high fluoride level of water.

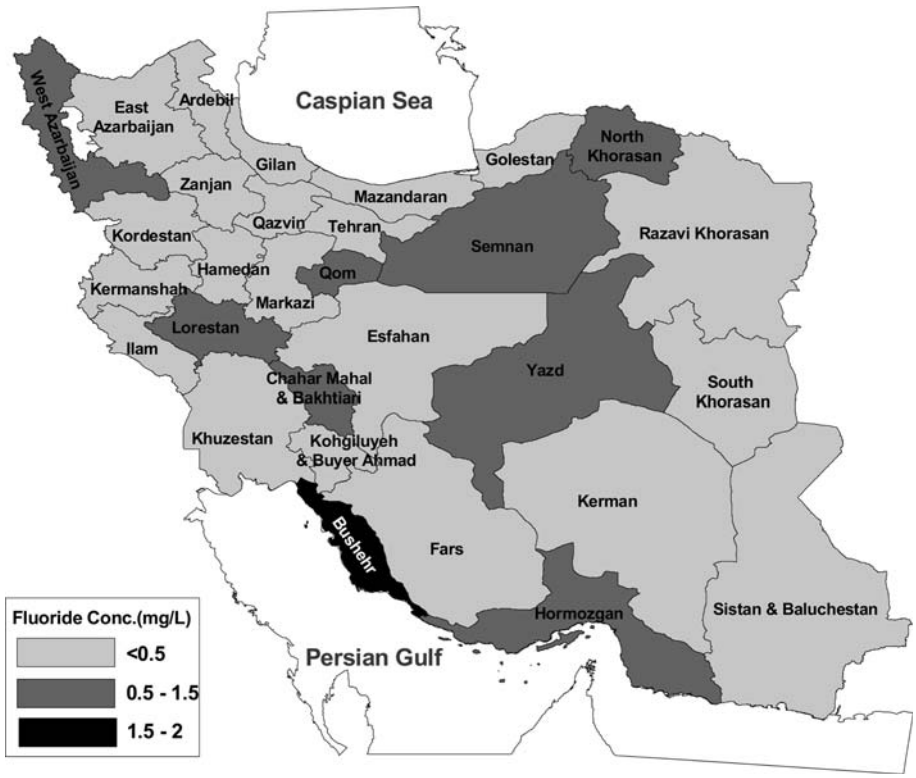

Fig. 1 Provincial mean of fluoride content in groundwater resources of Iran

According to Fig. 1, only in Bushehr, the provincial mean concentration of fluoride was higher than the WHO guideline value of 1.5 mg/L (1.86 ± 0.86 mg/L). High fluoride level of drinking water in some districts of this province was also reported by Dobaradaran et al. (2008).

Figuers 2 and 3 illustrate flow rate distribution of the groundwater resources as a function of fluoride concentration. Figure 2 shows that in Golestan, Kermanshah, Kohgiluyeh & Buyer Ahmad and Ilam provinces, more than 90% extracted groundwater had a fluoride level lower than the minimum permissible level. As illustrated on Fig. 2, the portion of groundwater flowrate with elevated fluoride level (higher than 1.5 mg/L) in Bushehr, Hormozgan, Yazd, Fars and West Azarbaijen provinces was 45, 10, 7, 3 and 3%, respectively and higher than the other provinces. According to Fig 2, inadequate fluoride content in groundwater resources was found in all of the provinces excluding Bushehr while the problem of high fluoride level was considerable (equal or more than 1% of total flowrate) only in 23% (7 provinces) of the provinces.

According to Fig. 3, in 69.2% of extracted groundwater for municipal uses at nationwide level, fluoride concentration was lower than the minimum permissible level. Because of drinking water is accounted as the most important source for fluoride intake, in a number of countries such as the USA this element is added to drinking water supplies with insufficient fluoride content. In the USA, a survey on database of the Center of Disease Control for 10 states highlighted that drinking water was fluoridated in 57% of water supplies. Depending on the average daily temperature, in the country the recommended value for fluoridation of drinking water is in the range of 0.7–1.2 mg/L (Miller-Ihli et al. 2003; Fawell et al. 2006). Despite relatively widespread application of water fluoridation, because of adverse health effects related to elevated fluoride intake, fluoridation of drinking water is still debated (Takahashi et al. 2001). In addition, a number of acute fluoride intoxication incidents following overdosing of water fluoridation have been reported (Fawell et al. 2006). Regarding to current structure of water supply systems in Iran, safe fluoridation of drinking water is not feasible presently. It is recommended that in the areas with low fluoride level drinking water, fluoride intake is compensated by consumption of high fluoride content foods and beverages. Tea is the most popular beverage in Iran. Mahvi et al. (2006) investigated the fluoride content of some commercial brands of tea in Iran. The results of this study indicated that the fluoride levels of tea and tea liquor were in the ranges of 35–182 mg/kg and 0.53–2.60 mg/L, respectively. The authors estimated that fluoride intake from tea in Iran ranges between 1.06 and 5.20 mg/day, so tea can be as a major source of fluoride intake in the country. Before any planning for establishment of water fluoridation system, further studies are needed to determine

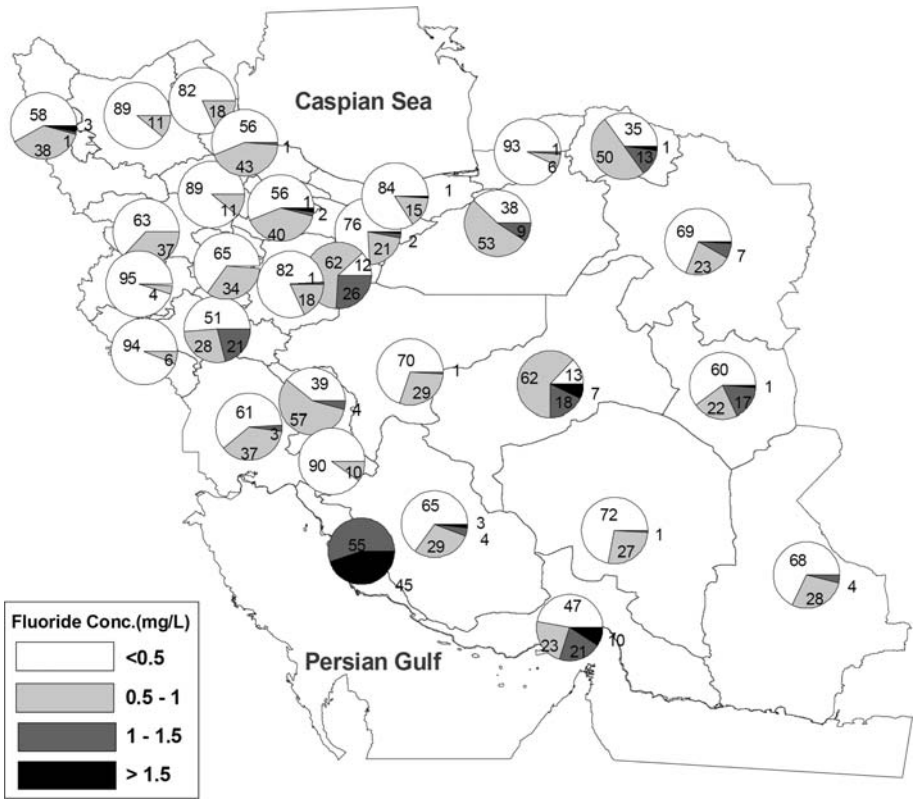

Fig. 2 Provincial flowrate distribution of the groundwater resources as a function of fluoride concentration (%)

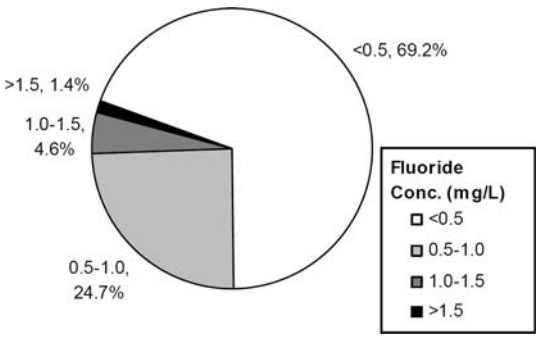

Fig. 3 Nationwide flowrate distribution of the groundwater resources as a function of fluoride concentration

fluoride content of foodstuffs and personal fluoride intake in the country.

In contrast, the problem of high fluoride concentration was not serious at national level, so that only in 1.4% of extracted groundwater, fluoride concentration was higher than the WHO guideline value (Fig. 3). Elevated fluoride content in drinking water resources have been reported in a number of countries, but in developing countries because of inadequate financial and technical supports, dealing with this issue have been found problematic and sophisticated (Fawell et al. 2006; Siddique et al. 2006; D'Alessandro et al. 2008). Paoloni et al. (2003) investigated fluoride level of groundwater resources in southeast of Argentina. Mean fluoride concentration was determined to be 3.8 mg/L and 97.1% of samples had fluoride content above the guideline value of 1.5 mg/L. In some areas of Thailand, fluoride concentration of drinking water was higher than 10 mg/L (Prasertsom 1998). In Turkey, Azbar and Türkman (2000) reported that fluoride concentration of drinking water in Eskişehir and Isparta was in the ranges of 1.9–7.5 and 3.8–4.9 mg/L, respectively. In rural regions of Northern Rajasthan, India the mean fluoride content of drinking water was 2.82 mg/L (Suthar et al. 2008).

In the areas that fluoride content of drinking water was excessive, for prevention of the adverse skeletal effects it is recommended as the first option that drinking water is provided from low fluoride content alternative sources. Defluoridation of drinking water is the other solution that is recommended where alternative sources are not available. The conventional technologies for the removal of excessive fluoride from drinking water include, mainly, adsorption using activated alumina and bone charcoal, contact precipitation, Nalgonda, ion exchange and membrane filtration (reverse osmosis and electrodialysis). Defluoridation systems can be established at point-of-use or at water works (Fawell et al. 2006). With regard to current status of community water systems in Iran, it is seemed that point-of-use systems is more feasible for the present time, but establishment of defluoridation systems at water works should be considered as a sustainable solution at long-term.

Review of the Iranian standard of drinking water quality for fluoride (Table 1) indicated that this standard is very strict in comparison with current fluoride standard in other countries and the WHO guideline. In addition, according to the results of this study, the standard is not enforceable regarding situation of the water resources and national financial, technical and institutional resources; therefore the standard should be revised on the basis of fluoride health concerns and national environmental, social, economic and cultural conditions.

In the present study, fluoride level in all of the groundwater resources that used as the source of drinking water in urban areas of Iran was monitored. The nationwide mean fluoride level in the groundwater resources was found to be lower than the minimum permissible level of 0.5 mg/L. Highest fluoride concentration in an individual water sample was 5.00 mg/L that was observed in Maku City, West Azarbaijan Province while highest provincial mean concentration of fluoride was found to be 1.86 mg/L that was reported in Bushehr Province. Elevated fluoride level that is the main problem of water quality concerning fluoride was observed only in 1.4% of the groundwater flowrate. Two recommendations are offered for dealing with the problem: the first option that has higher priority is provision of drinking water from alternative sources and the other is defluoridation of drinking water by point-of-use systems.

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